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COMMITTEE ON AVIATION ENVIRONMENTAL PROTECTION (CAEP)

FORECASTING AND ECONOMIC ANALYSIS SUPPORT GROUP (FESG)
MODELLING AND DATABASES GROUP (MDG)

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SUMMARY OF UPDATES FROM THE M.04/F.07 COST BENEFIT ANALYSES TASKS

Presented by the Cost Benefit Analysis (CBA) group

SUMMARY

During the MDG-FESG/1 meeting in Konstanz, the Cost Benefit Analysis group was formed to address the remits of tasks; *F.07 Evaluation of CBA* aimed at Evaluating how cost-benefit assessment might support decision-making in CAEP and *M.04 Identification of Assessment Tools* focusing on the identification and evaluation of tools for including noise, LAQ and GHG impacts (including monetization) tools for use as part of future CAEP assessments.
This paper focuses on (1) the review of definitions of cost benefit analyses (2) initial identification of tools and methodologies considered for documentation, (3) framework for documenting tools and methodologies, (4) preliminary documentation of tools and methodologies, (5) initial discussion on pros and cons of use of CBAs for CAEP purposes.
Section 7 provides actions to MDG-FESG.

1. INTRODUCTION

1.1 During the MDG/FESG/1 meeting in Konstanz, the Cost Benefit Analysis group was formed to address the remits of tasks; ***F.07 Evaluation of CBA*** aimed at Evaluating how cost-benefit assessment might support decision-making in CAEP and ***M.04 Identification of Assessment Tools*** focusing on the identification and evaluation of tools for including noise, LAQ and GHG impacts (including monetization) tools for use as part of future CAEP assessments. These tasks align with the ISG task I.07.

1.2 The Cost Benefit Group is composed of 13 members from MDG/FESG. It held 4 teleconferences on May 26th, June 27th, July 18th and August 15th. This report presents updates on the ongoing tasks. This includes; (1) the review of definitions of cost benefit analyses (2) set of tools and methodologies considered for documentation, (3) framework for documenting tools and methodologies, (4) preliminary documentation of tools and methodologies, (5) potential pros and cons of use of CBAs for CAEP purposes.

2. REVIEW OF DEFINITIONS OF COST BENEFIT ANALYSIS (CBA)

2.1 In order to provide a solid context for future work on CBA tools, methodologies, assumptions and on how CBA could be used in the context of CAEP decision making, the CBA group started by conducting a literature review of definitions and scope of Cost Benefit Analyses used by organizations conducting such analyses. In addition, the group reviewed and highlighted the nuances between Cost Benefit Analysis (CBAs) vs. Cost Effectiveness Analysis (CEAs).

2.2 Overview of Differences between Cost Benefit Analysis vs. Cost Effectiveness Analysis

2.2.1 Cost Benefit Analysis (CBA) and Cost Effectiveness Analysis (CEA) both provide analytical frameworks that are useful for evaluating the outcomes attributable to a particular policy (e.g., ICAO emissions standard). These approaches are both in widespread use and are often required by governments to be used as part of any regulatory or investment decision making process [1]. While both frameworks allow for developing a rigorous approach to analysing policies, there are important differences between them that make each technique more suitable for particular situations.

2.2.2 ***Cost Benefit Analysis (CBA);*** The unique feature of CBA is that it presents a net benefit measure denominated in monetary terms that includes most, or all, of the quantifiable economic impacts of a policy or intervention that is under consideration. Through this approach, it is possible to evaluate and compare different policy options using a common measure (monetary units), and to identify the option that maximizes net benefits. By presenting all costs and benefits in monetary terms, a CBA allows for examining a range of different effects of a policy. As an illustration, monetizing the economic damages caused by CO_2 emissions through their contribution to climate change enables the reduction in those damages from a policy that lowers emissions to be added to other economic benefits (e.g., savings in fuel costs), and allows their total to be compared to the policy's costs.

2.2.3 ***Cost Effectiveness Analysis (CEA);*** In contrast, CEA focuses on a single outcome of a policy – usually measured in physical units, rather than as an economic value – and presents it in terms of a ratio showing the average cost at which alternative policies can achieve that same outcome. Although this enables a ready comparison of the costs for achieving that outcome via different policies or delivery approaches, it restricts the focus to a single impact and excludes the value of other benefits that different policies may also provide. For example, in the CO_2 analysis CEA, the impact of central interest was tonnes of CO_2 emissions avoided, and CEA was used to compare the cost per tonne that could be avoided by relying on different stringencies. While this approach does not require monetizing all of the relevant benefits and costs of each policy, it is best suited for comparing a series of policies that are all intended to achieve the same outcome (e.g., reducing CO_2 emissions).

2.3 Summary of Definitions across Sources Reviewed to Date

2.3.1 To provide robust context for future work, several definitions of CBA from various governments and international organizations were reviewed. It was observed that the core-concept of CBA is similar across these various organizations. See Appendix A for additional details on definitions.

3. LIST OF TOOLS AND METHODOLOGIES CONSIDERED FOR DOCUMENTATION

3.1 The CBA group has started to identify tools that are being documented as part of the M.04 task remit. The following table provides an overview of the set of tools that are currently being considered for documentation.

Cost Benefit Analysis (CBA) Tools	
Acronym	**Description**
APMT–Impacts	Aviation environmental Portfolio Management Tool (APMT)-Impacts if part of the FAA Tool Suite. The APMT-Impacts estimates the environmental impacts of aircraft operations through changes in health and welfare endpoints for climate, air quality, and noise. It is part of a series of tools based on the latest research understanding to provide a thorough assessment of how changes to one or more aviation technologies or operations will affect many other aspects of aviation and society.
CBA Tools Used in EPA Analyses	EPA develops Regulatory Impact Analyses (RIAs) to support the development of national mobile source regulations that include estimates of the projected changes in ambient concentration, the incremental costs, and the quantified/monetized human health benefits of attaining new mobile source standards for the control of criteria and toxic pollutants. As relevant, they also discuss climate change impacts and the incremental monetized benefits of reducing greenhouse gas emissions, such as carbon dioxide and methane.
Aviation Integrated Modeling (AIM)	*Developed in the U.K, AIM is a policy assessment tool for aviation, environment and economic interactions at local and global levels, now and into the future*
DLR	*Economic assessment tool developed by DLR for technological developments, operational procedures and regulatory instruments*
EUROCONTROL CBA	*Model to facilitate decision-making by understanding the global impact on ATM performance of any proposed change, thus reducing investment risk.*
Generic Approach for Cost Benefit Analysis (CBA)	
Acronym	**Description**
World Bank CBA	*Determines if the overall economic benefits of a proposed project exceed its costs (including environmental), and to help design the project in a way that produces a solid economic rate of return.*
OECD CBA	*Tool to force the decision-maker to look at who the beneficiaries and losers are in both the spatial and temporal dimensions.*

4. FRAMEWORK FOR DOCUMENTING TOOLS AND METHODOLOGIES

4.1 In order to document the Cost Benefit Analysis tools, the CBA group reviewed CAEP documents on documentation of tools as a starting point for the development of a framework/format for documenting CBA tools.

4.2 Sources of Background Information for Documentation of Tools used within CAEP

4.2.1 The following references include previous CAEP evaluation process of various tools.

Paper Number	Description
CAEP8_MODTF_9_WP05_Model_and_Database_Evaluation_090917	Summary of Noise Cost Model, NOx cost model and APMT
CAEP/7-IP/2	IRTG Report
CAPE/7-IP/3	FESG report to steering group
CAEP/6 WP/19	FESG Executive Summary of NOx Stringency Options
CAEP/6 IP/13	FESG Executive Summary of NOx Stringency Options
CAEP/10 IP/4	MDG and FESG model and database evaluation process

4.3 Preliminary Framework for Documenting Tools

4.3.1 Based on the review of CAEP documents, the CBA group established an initial framework for documenting the CBA tools.

4.3.2 ***Documentation of individual tools;*** each tool is being documented using a consistent structure and format as described below.

1. Overview of Tool/Model
2. Assumptions, Input Data and Modeling Approach
3. Illustrative Case Study
4. Sample Output
5. References

4.3.3 ***Comparison of Tools;*** following the documentation of individual tools, comparisons of key components of the tools are being performed in order to identify commonalities and contrast differences.

5. SUMMARY OF ONGOING DOCUMENTATION OF CBA TOOLS

5.1 The following section provides a summary of CBA tools reviewed to date. Appendix 1-6 provides additional details for each of the tools.

5.2 Preliminary Summary of Format for Documentation of Cost Benefit Analysis tools reviewed to date

Tool	Geographic Coverage	Impact Type	Effects/Metrics Modeled	Primary Impact Metrics: Physical	Primary Impact Metrics: Monetary
APMT – Impacts	Global and US	Climate	CO_2, NO_x-CH_4, NO_x-O_3	Globally-averaged surface ΔT	Net Present Value of Mitigation Costs in US$
		Air Quality	$PM_{2.5}$	Premature mortalities	
		Noise	Area and Population Exposure, Housing Value, Rental loss	Population Impacted	
EUROCONTROL CBA	Europe	Climate	CO_2, H_2O, SO_2	Total CO_2 Equivalent	Average costs per PKM and TKM by mode
		Air Quality	NO_x,PM_{10},$PM_{2.5}$	Premature mortalities, Biodiversity and crop losses, Building & Material damages	
		Noise	Area and Population Exposure	Population Impacted	
Tools Used in EPA Analyses	Global and US	Climate (global)	CO_2, N_2O, CH_4	Total GHG emissions change	Social Cost of Carbon (SCC), Social Cost of Methane (SC-CH4), Social Cost of Nitrous Oxide (SC-N2O)
		Air Quality	NO_x,PM_{10},$PM_{2.5}$	Surface temperature change Sea level rise Ocean acidification (MAGICC)	n/a
		Noise			
Aviation Integrated Modeling	Global	Climate	NO_x, CO_2, H_2O, SO_2	Radiative impact/emissions reduction	Marginal Abatement Costs (€/person/year)
		Air Quality	NO_x,PM_{10},$PM_{2.5}$	Emissions concentration	
		Noise	Contours/Population Exposure	Population Impacted	
DLR	Europe	Climate	CO_2, H_2O, SO_2	Rising sea levels/crop shortfalls	Net Damage Costs (in €)
		Air Quality	PM_{10},$PM_{2.5}$	Changes in mortality/morbidity	
		Noise	Area and Population Exposure	Changes in mortality/morbidity	

6. INITIAL DISCUSSION HOW COST BENEFIT ANALYSES MAY BE USED FOR THE PURPOSES OF CAEP DECISION MAKING (TASK F.07)

6.1 While it is expected that the majority of the work on this task (i.e., F.07) will take place during the second and third year of the CAEP/11 cycle, the CBA group has started to evaluate how cost-benefit assessment might support decision-making in CAEP.

6.2 The CBA group started to discuss the following themes; (1) How are current decisions made in the CAEP process (2) What are the limitations of current approaches and potential needs for information going forward (3) What additional information could CBA bring and (4) How could CBA be used in the decision process.

6.3 Considerations discussed to date include;

- ***Input needed to conduct CBA***; some members noted that it would be valuable to identify required input to perform a CBA and how consensus on values and ranges is achieved.
- ***Uncertainty*** in input and output metrics; some members observed that some input metrics may be associated with significant uncertainty and urged the group to consider how uncertainty will be propagated in the tools, communicated to CAEP members and how it may impact the CAEP decision making process.

7. ACTION BY MDG-FESG

7.1 MDG-FESG is invited to:

a) Consider the content of this paper and updates from the CBA group on ongoing tasks M.04 and F.07,

8. APPENDIX A: SUMMARY OF DEFINITIONS ACROSS SOURCES REVIEWED

8.1.1 **Government of Canada** [2]: A CBA identifies and "measures the economic benefits and costs" of regulatory actions, which "serve as an essential input into the design process of regulatory actions." "The cost-benefit analysis should be guided by the principle of proportionality. In other words, the effort to do the cost-benefit analysis should be commensurate with the level of expected impacts on Canadians".

8.1.2 **German Aerospace Center (DLR)** [3]: A CBA is an "economic assessment of technological developments, operational procedures and regulatory instruments". It measures the "positive and negative effects of aviation" on a "uniform basis in terms of a monetary value."

8.1.3 **U.S. Environmental Protection Agency (EPA)** [4]: "A BCA evaluates the favorable effects of policy actions and the associated opportunity costs of those actions. It answers the question of whether the benefits are sufficient for the gainers to potentially compensate the losers, leaving everyone at least as well off as before the policy. The calculation of net benefits helps ascertain the economic efficiency of a regulation."

8.1.4 **Eurocontrol** [5]: "A CBA is an examination of all necessary costs related to the production and consumption of an output[1], independently of who bears the costs. These costs are then weighted against the expected benefits resulting from the materialization of the output. In particular, in the world of Air Traffic Management, the output object of study is usually an investment or project that only delivers the desired benefits after some years have passed. A key aspect of CBAs is the consideration of the times at which costs are paid and at which benefits are accrued. All the necessary investments and the expected benefits are transformed into a monetary value in the form of an expected Net Present Value (NPV)."

8.1.5 **U.S. Federal Aviation Administration (FAA)** [6]: "Benefit-cost analysis seeks to determine whether or not a certain output shall be produced and, if so, how best to produce it." It "calls for the examination of all costs related to the production and consumption of an output, whether the costs are borne by the producer, the consumer, or a third party." Benefits and costs must be "evaluated in the same unit of measurement."

8.1.6 **World Bank** [7]: The "benefits of an action are compared to its costs to determine whether the action is worth undertaking. This approach is commonly used to compare alternative options and requires that the environmental impacts be identified and that monetary values be placed on the outcomes. An example is the analysis of different air pollution control measures and the expected health benefits associated with each alternative."

8.1.7 **White House Guidance on CBA** [8]**:** "A distinctive feature of BCA is that both benefits and costs are expressed in monetary units, which allows you to evaluate different regulatory options with a variety of attributes using a common measure. By measuring incremental benefits and costs of successively more stringent regulatory alternatives, you can identify the alternative that maximizes net benefits. *(CBA allows for examining different effects of policy, e.g., cost of reduction in CO2, fuel cost savings, etc.)"*

[1] Output refers to the cost/investment related to a particular project (like a new airport or increased flight activity etc.) bounded by certain regulations to achieve desired benefits like emissions standard, reducing noise levels etc.

9. APPENDIX B: DOCUMENTATION OF TOOLS AND METHODOLOGIES

9.1 APPENDIX #B.1: APMT Impacts

9.1.1 Overview [9]

- APMT Impacts is a component of the FAA tools suite. It estimates the environmental impacts of aircraft operations through changes in health and welfare endpoints for climate, air quality, and noise. Impacts and associated uncertainties are simulated based on a probabilistic approach using Monte Carlo methods.
- APMT Impacts was developed by the Partnership for AiR Transportation Noise and Emissions Reduction, a multi-university research collaborative headquartered at MIT, is developing APMT for the U.S. Federal Aviation Administration, National Aeronautics and Space Administration (NASA), and Transport Canada.
- For the development of APMT Impacts, the following key documents were consulted: EPA Guidelines for Preparing Economic Analyses, OMB Circular A-4, Best Practices for Regulatory Analysis [10], UK HM Treasury Green Book on Appraisal and Evaluation in Central Government [11], UK Cabinet Office, Better Regulation Executive Regulatory Impact Assessment Guidance [12], OECD The economic appraisal of environmental projects and policies - A practical guide [13], Transport Canada Guide to Benefit Cost Analysis in Transport Canada [14], WHO Air Quality Guidelines for Europe [15], Resources for the Future, Cost Benefit Analysis and Regulatory Reform: An Assessment of the Science of the Art [16], Peer Review of the Methodology of Cost-Benefit Analysis of the Clean Air for Europe Programme [17], and Clean Air for Europe (CAFE) Programme Methodology for the Cost Benefit Analysis for CAFE Vol. 1 [18]

The schematic below illustrates APMT-Impacts relationship to the FAA Tool Suite, used for cost benefit analysis modelling.

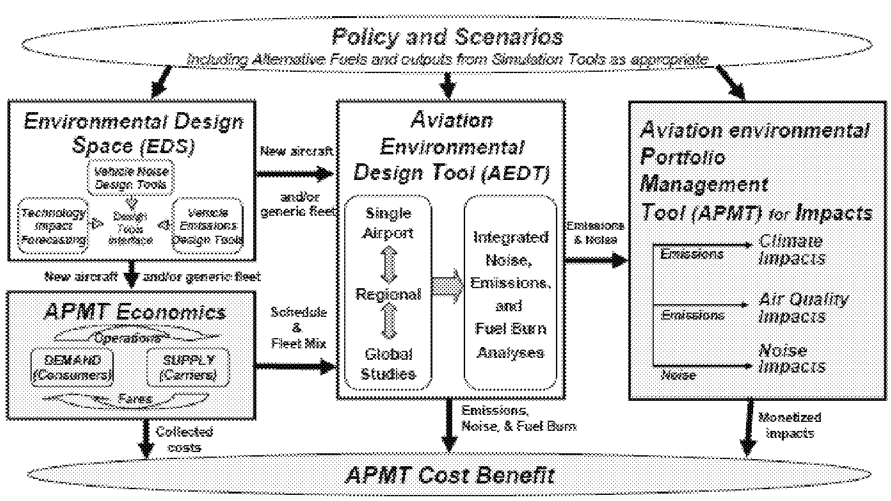


Figure 1: The FAA-NASA-Transport Canada Aviation Environmental Tool Suite

9.1.2 Summary of Model Inputs, Outputs, Modelling Approach and Assumptions

Module	Model Inputs	Source	Model Outputs	Modeling Approach	Assumptions
Noise	Noise Contours	AEDT [19]	• Population impacted • Annual noise damages (US$) • Housing value loss (US$)	• Noise contours are overlaid on population and housing data to estimate the physical and monetary impacts. • Monte Carlo method is used to determine the distribution of various factors [20]	• Conversion factor of 2.2 is used to convert Willingness-to-pay (WTP) from per person to per household
	Population & Housing Data	Various Sources			
Air Quality	Emissions Concentrations	AEDT	Incidences of • Premature mortality • Hospital admissions • Emergency Room visits etc. and their associated costs	• Calculation of changes in ambient concentration using CMAQ [21] • Changes in ambient concentrations are related to incidences of mortality and morbidity by using grid-level population data	• Population growth: 0% • Emissions from LTO cycle are considered • Value of Statistical Life: 6.3 million US $2000 • Cost of illness: $15,647
	Population Data	Various Sources			
Climate	Emissions Concentrations	AEDT	• Change in Radiative Forcing • Change in annual global temperature • Present value of climate damages for a unit impulse of emissions	• Impulse response modeling approach by Hasselmann [22] to estimate change in annual global temperature • Dynamic Integrated model of Climate and the Economy (DICE-2007) [23] to estimate aviation-specific climate damages	• Discount Rate: 2-7% • Global spatial scale analysis
	Economic data, Physical Capital and Labor	Various sources e.g., US Census data			

9.1.3 **Case Study:** Estimation of the global impacts of aviation-related noise using an income-based approach [24]

Study Objective: To assess the monetary impacts of aviation noise in order to evaluate policy alternatives and inform decision making. The proposed method is termed the income-based noise monetization model, and estimates individuals' Willingness to Pay for noise abatement based on city-level personal income, which differs from conventional approaches that rely on detailed real estate data. The second objective of the study is to describe how such a monetization model can be implemented within the framework of an aviation policy assessment tool, such as the United States Federal Aviation Administration's APMT-Impacts Noise Module, to estimate the worldwide economic impacts of aviation noise. Model is applied on 181 airports worldwide.

Method: The procedure for the development of the income-based noise monetization model is to start with a meta-analysis of existing hedonic pricing [HP] studies, derive a relationship for the Willingness to Pay (WTP) for noise abatement with respect to income and other significant explanatory variables, and use the resulting function for global benefit transfer of monetized aviation noise impacts.

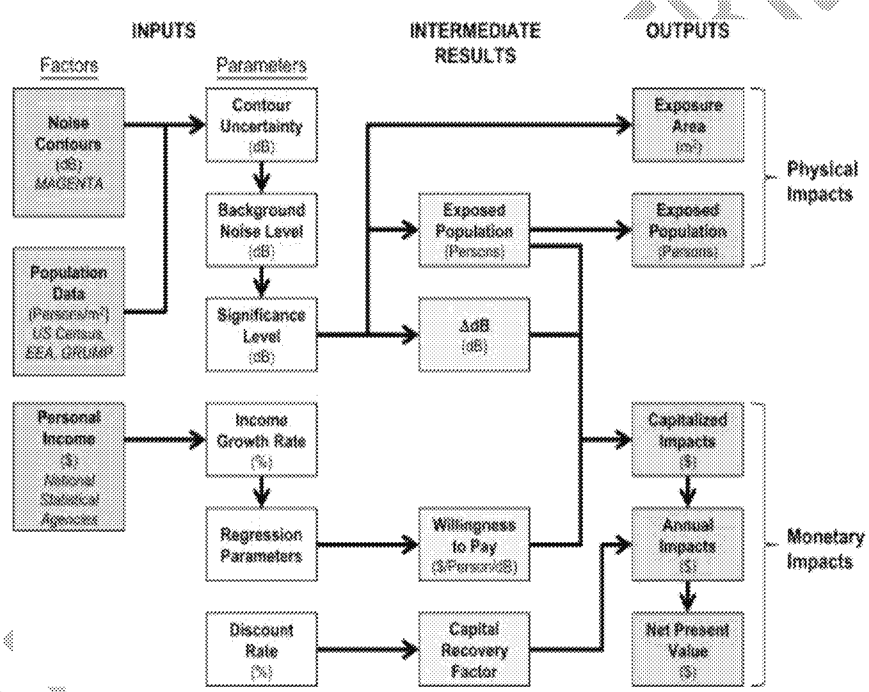


Figure 2: Schematic of income-based noise monetization model

9.1.4 Sample Outputs

Applying the new model to income, noise, and population data for 181 airports worldwide, the global capitalized monetary impacts of commercial aviation noise in 2005 are estimated to be $23.8 billion, with a Net Present Value of $36.5 billion between 2005 and 2035 when a 3.5% discount rate is applied.

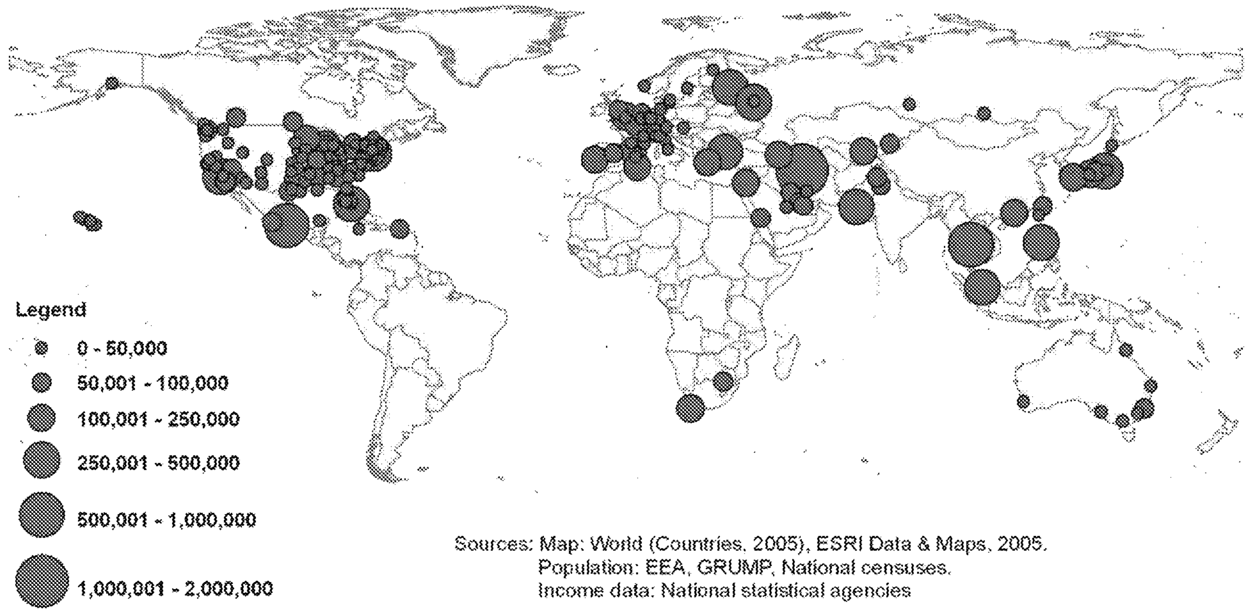


Figure 3: Number of people exposed to at least 55 dB DNL of aviation noise in 2005.

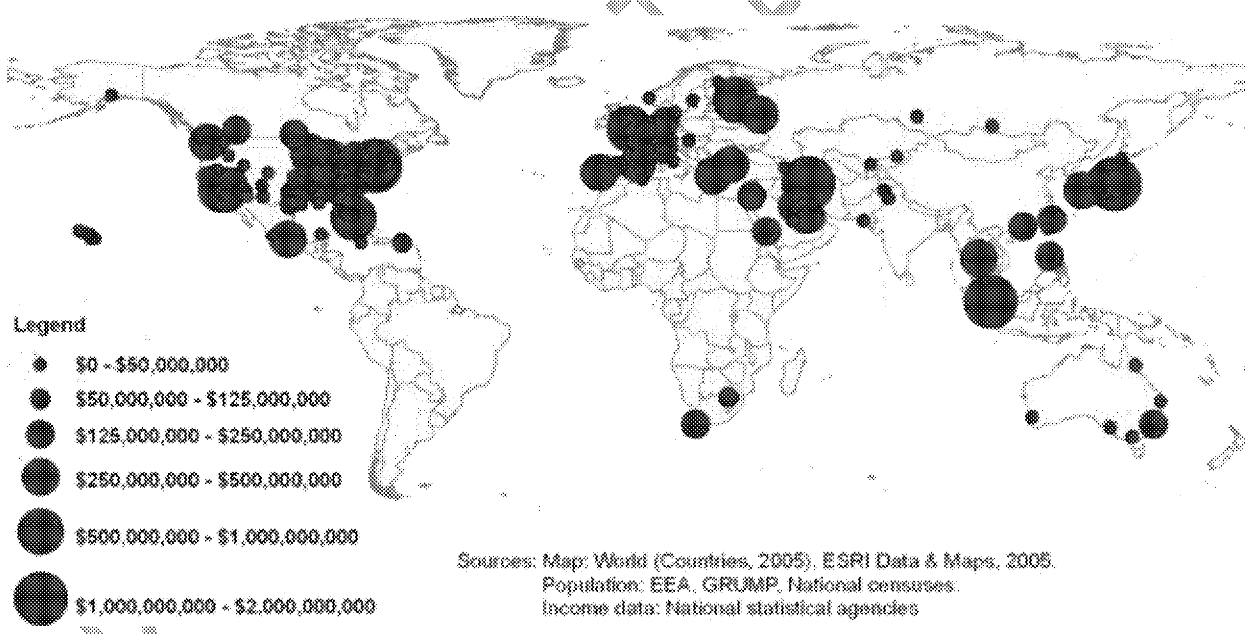


Figure 4: Geographic distribution of capitalized noise impacts around 181 airports in 2005.

9.5 APPENDIX #B.2: Environmental Protection Agency (EPA) Regulatory Impact Analysis (RIA)

9.5.1 Overview

- EPA develops Regulatory Impact Analyses (RIAs) to support the development of national mobile source regulations.

- EPA's mobile source Regulatory Impact Analyses (RIA) provide estimates of the projected changes in ambient concentration, the incremental costs, and the quantified/monetized human health benefits of attaining new mobile source standards for the control of criteria and toxic pollutants. As relevant, they also discuss climate change impacts and the incremental monetized benefits of reducing greenhouse gas emissions, such as carbon dioxide and methane.

- EPA fulfills the requirements of Executive Order 12866 and the guidelines of OMB Circular A-4, as well as its own guidelines for conducting economic analyses.[25]

5.5.2 Assumptions, Input Data and Modeling Approach

Module	Model Inputs	Source	Model Outputs	Modeling Approach	Assumptions
Air Quality (CMAQ)	1) Emissions for the base year and future year reference and control cases 2) Meteorology for the base year 3) Boundary concentrations for the base year from a global photochemical model	Air Quality Modeling Platform[26]	Hourly concentrations of ambient criteria and air toxic pollutants, at the 12km grid cell level, with 25 vertical layers up to 50 millibars, for the continental US, for the projected future year. Model predictions are used in a relative sense to estimate scenario-specific, future-year concentrations of PM2.5 and ozone. For example, we compare a 2040 reference scenario (a scenario without the mobile source standards) to a 2040 control scenario which includes the mobile source standards.	CMAQ is a non-proprietary computer model that simulates the formation and fate of photochemical oxidants, primary and secondary PM concentrations, acid deposition, and air toxics for given input sets of meteorological conditions and emissions. CMAQ includes numerous science modules that simulate the emission, production, decay, deposition and transport of organic and inorganic gas-phase and particle-phase pollutants in the atmosphere.	Meteorology and stationary source emissions remain constant in future years (i.e., consistent with the base year inputs)
Criteria Pollutant Benefits (BenMAP)	Ambient PM2.5 and Ozone Concentration Data Population Data	CMAQ US Census	Incidences of • Premature mortality • Hospital admissions • Emergency Room visits etc. and their associated monetized unit values	• Changes in exposure to population is calculated • Selection of health endpoints to develop health impact functions • Valuation of avoided health impacts • Use of Monte Carlo method for estimating random sampling error associated with the concentration response functions and economic valuation functions	• All fine PM particles irrespective of size are equally potent • Health impact function for fine PM particles is linear
Climate	Emissions Data	NEI	• Monetized estimates of the benefits of reducing GHG emissions.	EPA has applied the U.S. Government's estimates of the social cost of carbon (SC-CO_2) to the incremental CO_2 reductions. The USG developed the SC-CO_2 estimates using three integrated assessment models and recommended four SC-CO_2 values for use in regulatory analysis. See the OMB website for methodological details and the schedule of estimates.[27] EPA has also applied Marten et al. (2014) estimates of the social cost of methane (SC-CH_4) and social cost of nitrous oxide (SC-N_2O) to	• The four SC-CO_2 estimates are: average at discount rates 2.5, 3, and 5%, respectively, and the 95[th] percentile SC-CO_2 at a 3% rate. • SC-CO_2 estimates are specific to the year of emissions and increase over time. • SC-CO_2 estimates are global measures. • The SC-CH_4 and SC-N_2O estimates are consistent with the modeling assumptions

				incremental reductions in methane and nitrous oxide, respectively.[28]	underlying the $SC\text{-}CO_2$ estimates.
			• Temperature, sea level rise, ocean acidification	GHG and other emissions are used as inputs to an energy-balance climate model such as MAGICC or Hector.[29]	• Climate sensitivities from 1.5 to 6 degrees can be calculated

9.5.3 **Case Study**: Phase 2 GHG Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles

Objective: To provide an example of the methodology for estimating and monetizing the health benefits expected from reducing emissions from mobile sources.

Method:

- The CMAQ air quality model estimates air quality concentrations at 12km grid cell resolution.

- The Environmental Benefits Mapping and Analysis Program (BenMAP) is used to estimate the health benefits associated with reductions in ambient pollutant concentrations due to implementing the standards.

  EPA applied the U.S. Government's estimates of the social cost of carbon to the incremental CO2 reductions to estimate the benefits of CO2 reductions. EPA also estimated the benefits of non-CO2 greenhouse gas reductions by applying Marten et al. (2014) estimates of the social cost of methane and social cost of nitrous oxide to incremental reductions in methane and nitrous oxide, respectively.[30]

Social Cost of CO2, 2012 – 2050a (in 2013$ per Metric Ton)

Calendar Year	Discount Rate and Statistic			
	5% Average	3% Average	2.5% Average	3% 95th percentile
2012	$12	$36	$58	$100
2015	$12	$40	$62	$120
2020	$13	$46	$68	$140
2025	$15	$51	$75	$150
2030	$18	$55	$80	$170
2035	$20	$60	$86	$180
2040	$23	$66	$92	$200
2045	$25	$70	$98	$220
2050	$29	$76	$100	$230

Note:
[a] The $SC\text{-}CO_2$ values are dollar-year and emissions-year specific and have been rounded to two significant digits. Unrounded numbers from the current $SC\text{-}CO_2$ TSD were adjusted to 2013$ and used to calculate the CO_2 benefits.

Social Cost of CH4 and Social Cost of N2O, 2012 – 2050a (in 2013$ per Metric Ton)

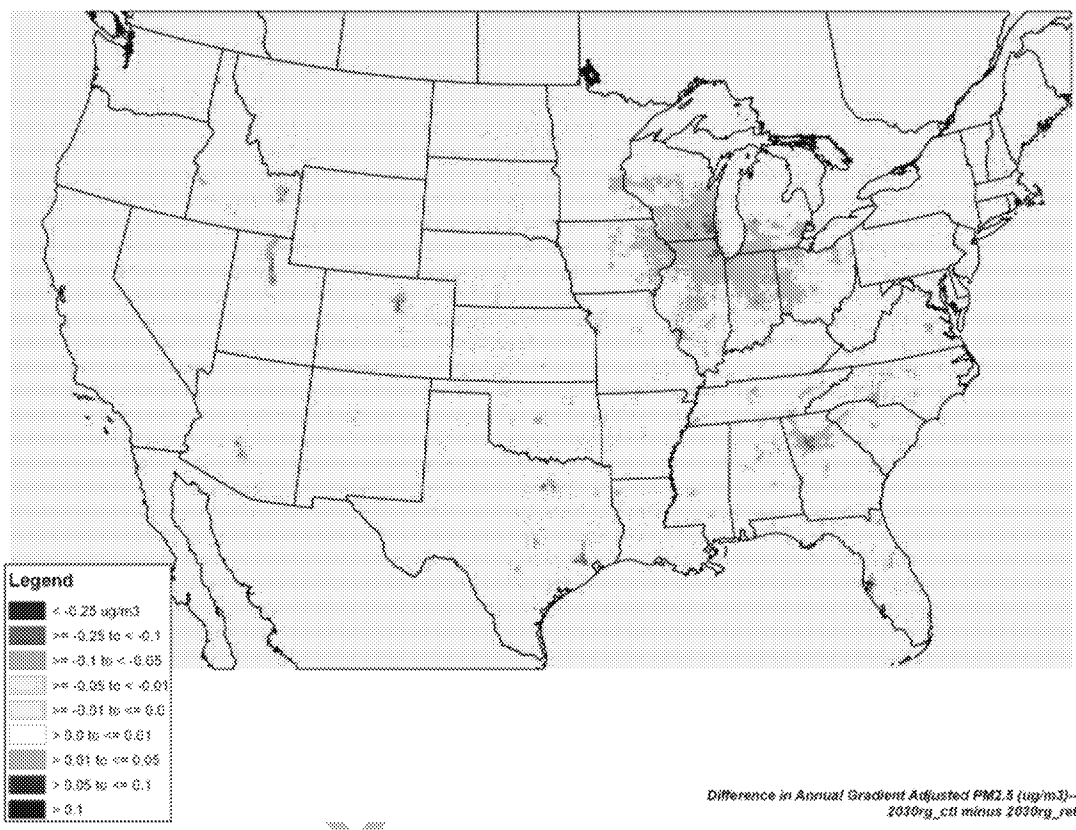
Year	$SC\text{-}CH_4$				$SC\text{-}N_2O$			
	5% Average	3% Average	2.5% Average	3% 95th percentile	5% Average	3% Average	2.5% Average	3% 95th percentile
2012	$440	$1,000	$1,400	$2,800	$4,000	$14,000	$21,000	$36,000
2015	490	1,100	1,500	3,100	4,400	14,000	22,000	38,000
2020	590	1,300	1,800	3,500	5,200	16,000	24,000	43,000
2025	710	1,500	2,000	4,100	6,000	19,000	26,000	48,000
2030	830	1,800	2,200	4,600	6,900	21,000	30,000	54,000
2035	990	2,000	2,500	5,400	8,100	23,000	32,000	60,000
2040	1,100	2,200	2,900	6,000	9,200	25,000	35,000	66,000
2045	1,300	2,500	3,100	6,700	10,000	27,000	37,000	73,000
2050	1,400	2,700	3,400	7,400	12,000	30,000	41,000	79,000

Note:
[a] The values are emissions-year specific and have been rounded to two significant digits, as shown in Marten et al. (2014). These rounded numbers were used to calculate the GHG benefits.

[b] The estimates in this table have been adjusted to reflect the minor technical corrections to the SC-CO2 estimates described above. See the Corrigendum to Marten et al. (2014), http://www.tandfonline.com/doi/abs/10.1080/14693062.2015.1070550

9.5.4 Sample Outputs

Projected Change in 2030 Annual PM2.5 Concentrations[31]



Estimated Monetary Value of Changes in Incidence of Health and Welfare Effects (millions of 2010\$)[32]

HEALTH ENDPOINTS		2030 (5TH AND 95TH PERCENTILE)
$PM_{2.5}$-Related Health Effects		
Premature Mortality – Derived from Epidemiology Studies[b,c]	Adult, age 30+ - ACS study (Krewski et al., 2009)	
	3% discount rate	**\$6,100 (\$910 - \$14,000)**
	7% discount rate	**\$5,500 (\$820 - \$13,000)**
	Adult, age 25+ - Six-Cities study (Lepeule et al., 2012)	
	3% discount rate	**\$14,000 (\$2,000 - \$33,000)**
	7% discount rate	**\$12,000 (\$1,800 - \$30,000)**
	Infant Mortality, <1 year – (Woodruff et al. 1997)	**\$13 (\$1.8 - \$32)**
Non-fatal acute myocardial infarctions		
Peters et al., 2001		
3% discount rate		**\$96**

		($21 - $230)
7% discount rate		**$93** **($19 - $220)**
Pooled estimate of 4 studies		
3% discount rate		**$10** **($2.6 - $27)**
7% discount rate		**$10** **($2.4 - $27)**
Hospital admissions for respiratory causes[d]		**$5.9** **(-$1.6 - $11)**
Hospital admissions for cardiovascular causes		**$9.9** **($5.0 - $17)**
Emergency room visits for asthma[d]		**$0.15** **(-$0.02 - $0.29)**
Acute bronchitis (children, age 8–12)[d]		**$0.49** **(-$0.02 - $1.2)**
Lower respiratory symptoms (children, 7–14)		**$0.27** **($0.11 - $0.51)**
Upper respiratory symptoms (asthma, 9–11)		**$0.62** **($0.18 - $1.4)**
Asthma exacerbations		**$1.1** **($0.14 - $2.7)**
Work loss days		**$12** **($11 – $14)**
Minor restricted-activity days (MRADs)		**$34** **($20 - $49)**
Ozone-Related Health Effects		
Premature Mortality, All ages – Derived from Multi-city analyses	Bell et al., 2004	**$1,100** **($150 - $2,800)**
	Huang et al., 2005	**$1,600** **($220 - $4,100)**
	Schwartz, 2005	**$1,700** **($220 - $4,400)**
Premature Mortality, All ages – Derived from Meta-analyses	Bell et al., 2005	**$3,600** **($510 - $8,800)**
	Ito et al., 2005	**$5,000** **($740 - $12,000**
	Levy et al., 2005	**$5,100** **($760 - $12,000)**
Hospital admissions- respiratory causes (adult, 65 and older)		**$21** **($2.5 - $39)**
Hospital admissions- respiratory causes (children, under 2)		**$3.7** **($1.9 - $5.4)**
Emergency room visit for asthma (all ages)		**$0.14** **(-$0.003 - $0.41)**
Minor restricted activity days (adults, age 18-65)		**$43** **($19 - $73)**
School absence days		**$21** **($9.3 - $31)**

[a] Monetary benefits are rounded to two significant digits for ease of presentation and computation. PM and ozone benefits are nationwide.
[b] Monetary benefits adjusted to account for growth in real GDP per capita between 1990 and the analysis year (2030).
[c] Valuation assumes discounting over the SAB recommended 20 year segmented lag structure. Results reflect the use of 3 percent and 7 percent discount rates consistent with EPA and OMB guidelines for preparing economic analyses.
[d] The negative estimate at the 5th percentile confidence estimate for this morbidity endpoint reflects the statistical power of the study used to calculate this health impact. This result does not suggest that reducing air pollution results in additional health impacts.

Impact of GHG Emissions Reductions on Projected Changes in Global Climate Associated with the Final Program (Based on a Range of Climate Sensitivities from 1.5-6°C)

Variable	UNITS	YEAR	PROJECTED CHANGE
Atmospheric CO_2 Concentration	ppmv	2100	-1.2 to -1.3
Global Mean Surface Temperature	°C	2100	-0.0027 to -0.0065

Sea Level Rise	cm	2100	-0.026 to -0.058
Ocean pH	pH units	2100	+0.0006[a]

Note:
[a] The value for projected change in ocean pH is based on a climate sensitivity of 3.0.

- NOTE: APPENDIX IS A WORKING DRAFT ON DOCUMENTATION OF TOOLS –
- NOT INCLUDED IN MDG/FESG-2 WP – TBC -

9.6 APPENDIX #B.3: EUROCONTROL CBA

9.6.1 Overview

- EUROCONTROL developed the European Models for ATM Strategic Investment (EMOSIA) to conduct CBA analysis in Air Traffic Management (ATM) [33]. EMOSIA facilitates decision-making by understanding the global impact on ATM performance of any proposed change, thus reducing investment risk. EMOSIA applies the following two principles;
    - Iteration: proceeding by successive approximations, selecting what really matters for further improvements, reducing uncertainty accordingly by collecting more information and/or gaining more control on the project dimensions.
    - Interaction: fostering a continuous dialogue between all project stakeholders, involving them as early as possible with the aim of obtaining their ownership and buy-in.

Schematic shows a sample methodology to calculate impacts due to Climate change developed by CE Delft [34].

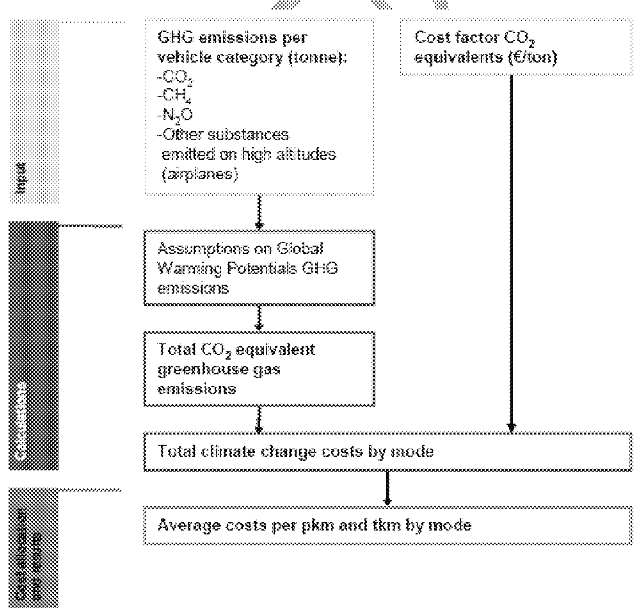


Figure 5: Methodology for climate change related costs

9.6.2 Summary of Model Inputs, Outputs, Modelling Approach and Assumptions

Module	Model Inputs	Source	Model Outputs	Modeling Approach	Assumptions
Noise	Nosie Map	HEATCO [35]	• Health Effects per Person and dB(A) • Cost of annoyance	• Estimation of the number of people affected by noise per vehicle type • Estimation of total noise costs by multiplying the number of people affected by the noise costs per person exposed	• Noise weighting factor: 1 • Population growth: 0%
	Population Density Data	Various Sources			
Air Quality	Emissions Concentrations	TREMOVE [36]	• Health costs • Biodiversity losses • Building and Material damages • Crop losses	Calculation of damage costs is based on impact pathway approach. Steps are: 1. Emissions 2. Transmission 3. Concentration (dose) 4. Impact/damage 5. Monetization 6. Costs	• Population growth: 0% • Value of Life Year: 40, 000 Euros • Cost of a case of chronic bronchitis: 200,000 Euros
	Cost factors (Euro per unit)	HEATCO			
Climate	Emissions Concentrations	TREMOVE	• Damage costs • Avoidance costs based on cost-effective analysis approach	• Assess total GHG emissions by type of vehicle per country • Calculate total CO_2 equivalent GHG emissions using Global Warming Potentials • Estimate total external costs related to global warming per country • Calculate the average climate change costs (per tkm/pkm)	• Discount Rate: 0.5-1% • Equal weighting for all countries
	Cost factor CO_2 equivalent (Euro/ton)	HEATCO			

9.6.3 **Case Study**: Calculation of Noise Costs in EU-27 for different Aviation noise levels [37]

Study Objective: To quantify negative impacts of noise on humans. The two negative impacts evaluated in this study are:

- Cost of Annoyance: Transport noise imposes undesired social disturbances, which result in social and economic costs like any restrictions on enjoyment of desired leisure activities, discomfort or inconvenience, etc.

- Health Damages: Noise levels above 85 dB(A) can cause hearing damage. Lower noise levels (above 60 dB(A)) may increase the risk on cardiovascular diseases (heart and blood circulation).

Method: Uses Bottom-up approach as per the following 3 steps:

1) Estimation of the number of people affected by noise per vehicle type

2) Estimation of total noise costs by multiplying the number of people affected by the noise costs per person exposed

3) Calculation of the average noise costs by allocating the total noise costs to the various transport modes by using specific weighting factors

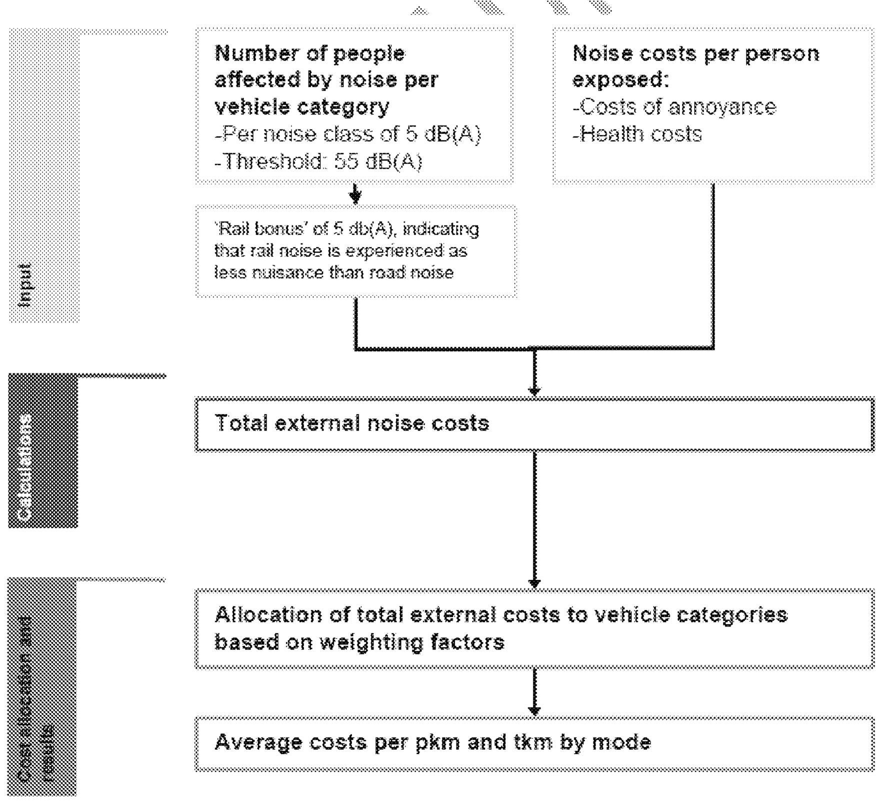


Figure 6: Methodology for noise related costs

9.6.4 Sample Outputs

Table 1: Number of people (in millions) exposed to noise from aviation

County	Noise levels Lden in dB(A)					
	55-59	60-64	65-69	70-74	>75	Total
Austria	0.008	0.001	0.000	0.000	0.000	0.009
Belgium	0.035	0.011	0.004	0.000	0.000	0.050
Bulgaria	0.052	0.032	0.021	0.001	0.000	0.105
Czech Republic	0.006	0.002	0.000	0.000	0.000	0.007
Denmark	0.001	0.001	0.000	0.000	0.000	0.001
Estonia	0.001	0.000	0.000	0.000	0.000	0.001
Finland	0.001	0.000	0.000	0.000	0.000	0.001
France	1.347	0.032	0.002	0.000	0.000	1.381
Germany	0.356	0.085	0.007	0.001	0.000	0.449
Greece	0.013	0.002	0.000	0.000	0.000	0.015
Hungary	0.222	0.065	0.002	0.001	0.000	0.290
Ireland	0.003	0.000	0.000	0.000	0.000	0.003
Italy	0.158	0.049	0.010	0.001	0.000	0.218
Latvia	0.002	0.001	0.000	0.000	0.000	0.003
Lithuania	0.009	0.003	0.001	0.000	0.000	0.013
Luxembourg	0.000	0.000	0.000	0.000	0.000	0.000
Netherlands	0.063	0.006	0.001	0.000	0.000	0.070
Norway	0.005	0.001	0.000	0.000	0.000	0.007
Poland	0.049	0.010	0.004	0.003	0.000	0.066
Portugal	0.003	0.001	0.000	0.000	0.000	0.005
Romania	0.012	0.011	0.006	0.000	0.000	0.029
Slovakia	0.002	0.001	0.000	0.000	0.000	0.002
Slovenia	0.000	0.000	0.000	0.000	0.000	0.000
Spain	0.135	0.019	0.006	0.001	0.000	0.160
Sweden	0.006	0.001	0.000	0.000	0.000	0.006
Switzerland	0.158	0.074	0.017	0.002	0.000	0.251
United Kingdom	0.789	0.214	0.056	0.010	0.001	1.069
Total	3.432	0.620	0.136	0.020	0.001	4.210

Table 2: Noise Costs (€2008/person/year) for different noise levels: aviation

Countries	Noise levels Lden in dB(A)				
	55-59	60-64	65-69	70-74	75-79
Austria	133	228	323	476	620
Belgium	128	219	310	457	594
Bulgaria	56	96	135	195	251
Czech Republic	109	186	264	381	492
Denmark	132	227	321	473	615
Estonia	93	160	226	324	417
Finland	125	214	303	446	580
France	120	205	291	429	558
Germany	110	188	266	394	513
Greece	103	176	250	364	472
Hungary	88	152	215	312	403
Ireland	167	287	407	595	772
Italy	113	194	275	406	528
Latvia	79	136	193	278	357
Lithuania	80	137	194	279	359
Luxembourg	200	343	485	709	918
Netherlands	133	228	323	477	620
Norway	177	303	429	628	814
Poland	59	101	144	209	271
Portugal	82	140	199	294	382
Romania	71	121	171	244	314
Slovakia	103	177	251	360	464
Slovenia	105	180	255	372	482
Spain	117	200	283	414	537
Sweden	130	223	316	464	603
Switzerland	123	210	298	444	579
United Kingdom	125	214	303	447	582

9.7 APPENDIX #B.4: Aviation Integrated Modeling (AIM)

9.7.1 Overview

- AIM [38] was originally developed at Cambridge University's Institute for Aviation and the Environment. It is now based at University College London's Energy Institute under ACCLAIM [39]. The tool is capable of estimating global environmental impacts and its associated economic impacts.

- AIM consists of 7 modules as shown in Figure 7 and has the following capabilities;

    - ***Policy Assessment***: Each module provides an input site for candidate "policy levers" that manipulate the evolution of the air transportation system and hence allows an assessment of their environmental and economic impacts.
    - ***Trade-Off Analysis***: Key interdependencies are captured, allowing data transfer and feedback between the modules. This allows complex trade-offs between competing environmental (e.g. noise vs. CO_2 vs. NOx) and economic metrics
    - ***Tailored Resolution***: The temporal and spatial resolution of each module can be tailored to the application being considered.
    - ***Module Substitution***: Module definitions from other developers can be substituted to examine their interactions within the wider integrated structure (subject to appropriate interfaces existing).
    - ***Future Growth Potential***: The modular architecture allows natural growth and extension of capabilities.

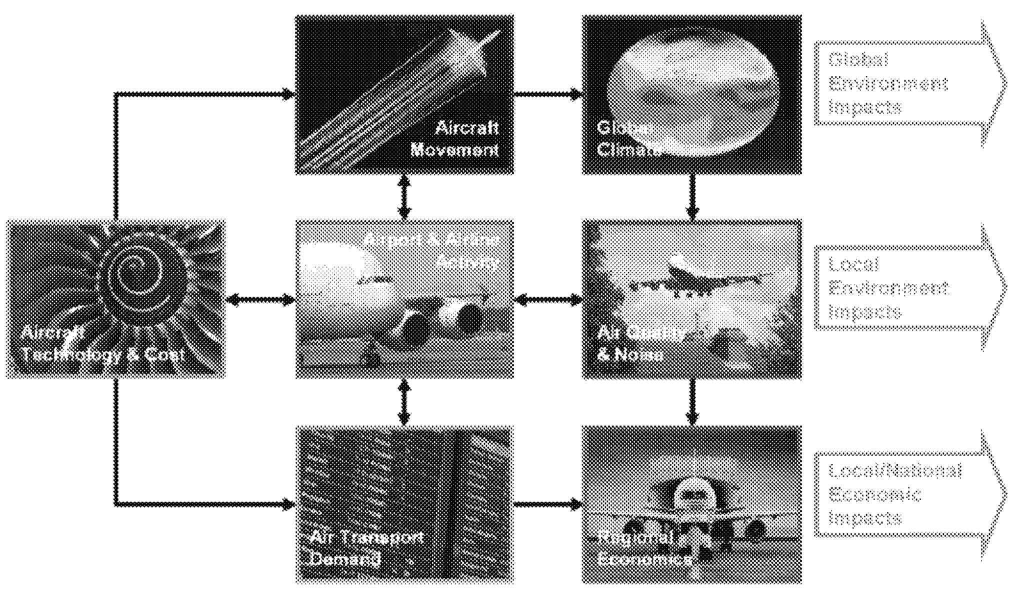


Figure 7: AIM's architecture with its 7 modules

9.7.2 Summary of Model Inputs, Outputs, Modelling Approach and Assumptions

Module	Model Inputs	Source	Model Outputs	Modeling Approach	Assumptions
Noise	Nosie contours Population exposure	INM [40] /AEDT Or NMSim [41]	• Property valuation impacts • Societal Costs of location within a given noise contour	• Noise impacts are assessed of key variables including fleet mixes and routine structures • The noise metrics are fed to the Regional Economics module	
Air Quality	Emissions Concentrations	ETMS [42] /AEDT or Air Quality Monitoring Stations at Airports	• Health costs around airport • Building and Material damages	• Local air quality (LAQ) contours are fed into Regional Economics Module • Regional module allows imposing of several policy measures Note: No public information available on LAQ Costing model	
Climate	Aircraft Movements Data Meteorology Data	ETMS ECMWF [43]	• Global average temperature potential • CO_2 abatement costs	• Airborne emissions from Aircraft Movement Module is fed into Global Climate Module • Climate parameters are calculated and fed into Local Air Quality & Noise module	

9.7.3 **Case Study:** Costs of mitigating CO_2 emissions from passenger aircraft [44]

Study Objective: To provide a techno-economic analysis of CO_2 emission mitigation options for the domestic US aviation sector, the world's single largest air transportation system. The study focuses on narrow-body aircraft with 100–189 seats, which generate 80% of revenue passenger kilometres (RPKs)

Method: Analysis is based on an aircraft fleet composition and CO_2 emissions model that allows: a realistic simulation of the introduction of improvements to existing aircraft (retrofits) and of new aircraft generations; a robust assessment of the CO_2 emissions mitigation potential and cost of all mitigation options related to the aircraft age cohort (those aircraft of a given vintage) that would be affected; and simulation of the scheduling of aircraft retrofits in line with major maintenance checks to minimize the opportunity costs of non-available aircraft. In addition, all relevant cost elements affecting airline operating costs are accounted. Other key parameters include;

- CO_2 mitigation costs are calculated in US$/per tonne of CO_2
- As a mitigation cost metric, cumulative (2012–2050) marginal abatement costs is employed, discounted to 2012 at a rate of 5%

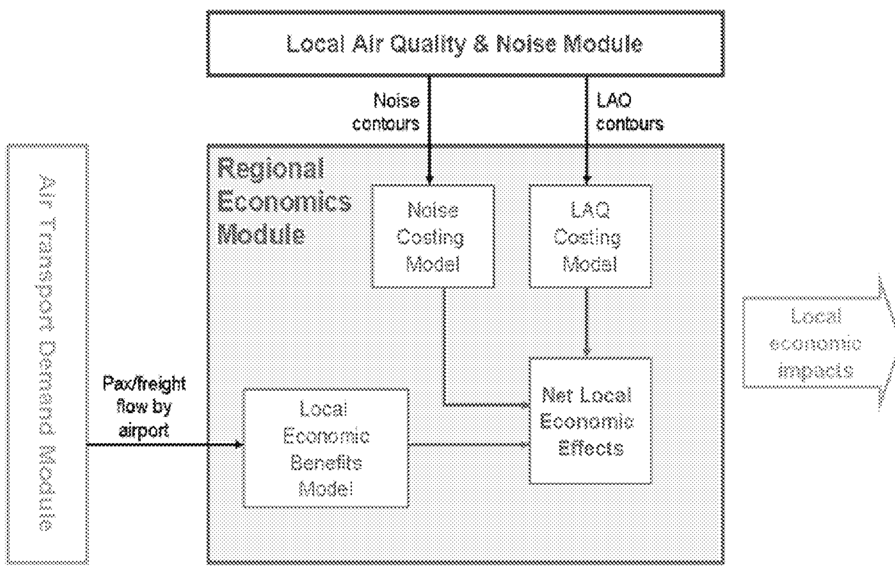


Figure 8: Schematic shows Regional Economic Impacts Module

9.7.4 **Sample Outputs**

Table 3: Techno-economic characteristics of CO_2 mitigation technologies and synthetic fuels at a fuel price of US$3.1 per gallon (crude oil price of US$100 per bbl).

	Year of introduction	Application potential* (% of fleet)	Life cycle CO_2 emissions reduction (% per aircraft)	Payback period† (yr)	Mitigation costs† (US$ per tonne of CO_2)
Retrofits					
Blended winglets	2015	25	3.0 (2–4)	3.3	−80
Carbon brakes	2015	13	0.35 (>0)	1.0	−10
Re-engining	2016	70	12.5 (1–12)	15	830
Cabin weight reduction					
Mild	2015	0	1.2	2.9	−110
Aggressive	2015	50	2.1 (0.6–1.6)	5.3	70
Electric taxiing	2018	50	2.8 (1.5–4)	2.1	−170
Intermediate-generation aircraft					
A320NEO/B737MAX/CSeries	2016	100	15‡	2.9	−250
Next-generation aircraft					
Evolutionary	2035	0	30‡	6.2	−160
Open rotor	2035	100	40‡	9.7	−70
Synthetic fuels					
Biomass-to-liquids (BTL)	2020	15–30§	13–26§	0–∞§	−10–70

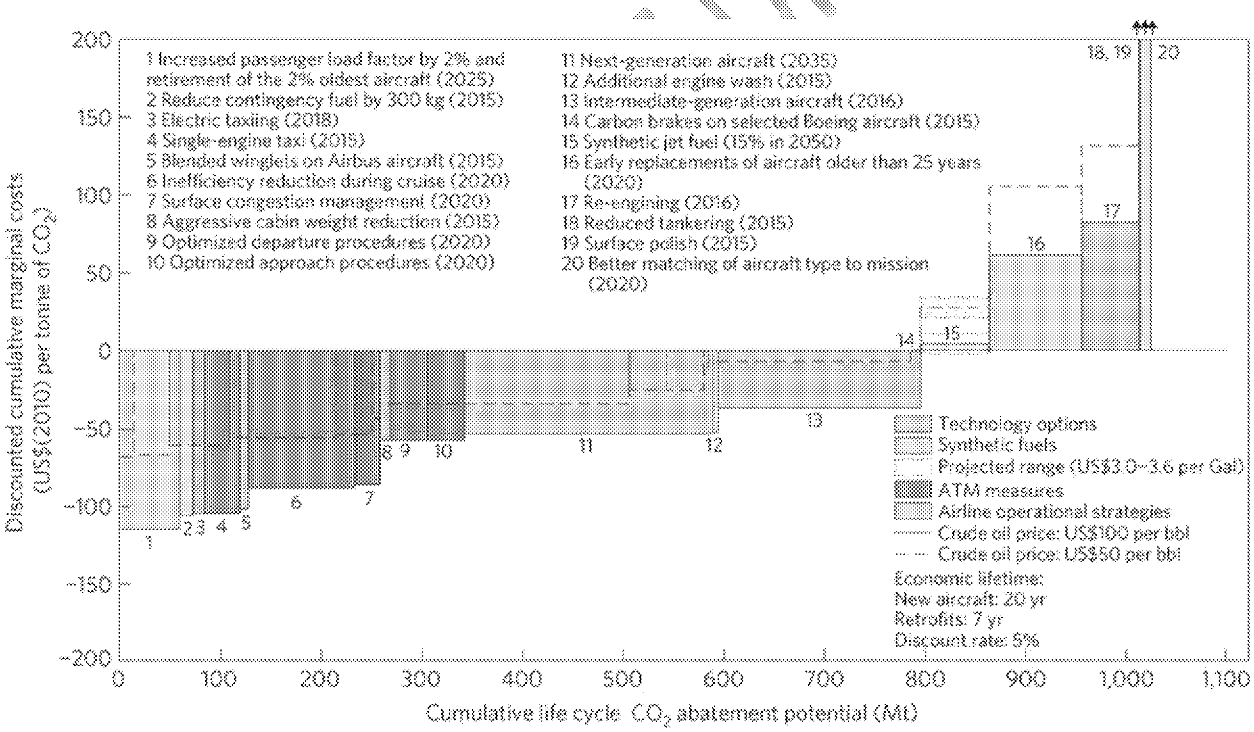


Figure 9: Discounted marginal abatement costs for cumulative (2012–2050) life cycle CO_2 emissions from narrow-body aircraft in US domestic passenger service

5.4 APPENDIX #B.5: DLR COST BENEFIT ANALYSIS MODEL

9.7.1 Overview

- Developed by DLR Institute of Air Transport and Airport Research [45]. The analysis is conducted in a chain of different models, which link emissions, physical impacts and economic impacts. Various metrics are monetized with values of the marginal damage cost per ton of CO_2

- Following capabilities are under development:

    - Climate Modeling: Economic valuation of climate change is done in terms of damage costs (€ / t CO_2-equivalent)
    - Local Air Quality: Economic valuation of local pollutants are done in terms of damage cost values (in € / t of pollutant)
    - Aircraft Noise: Monetization approach involves the connection of population exposed to aircraft noise with damage costs dependent on L_{den}
    - Accessibility/Connectivity: Monetization of the utility dimension "travel time savings" is already incorporated in the airport choice model and is used for the quantification of connectivity benefits [46].

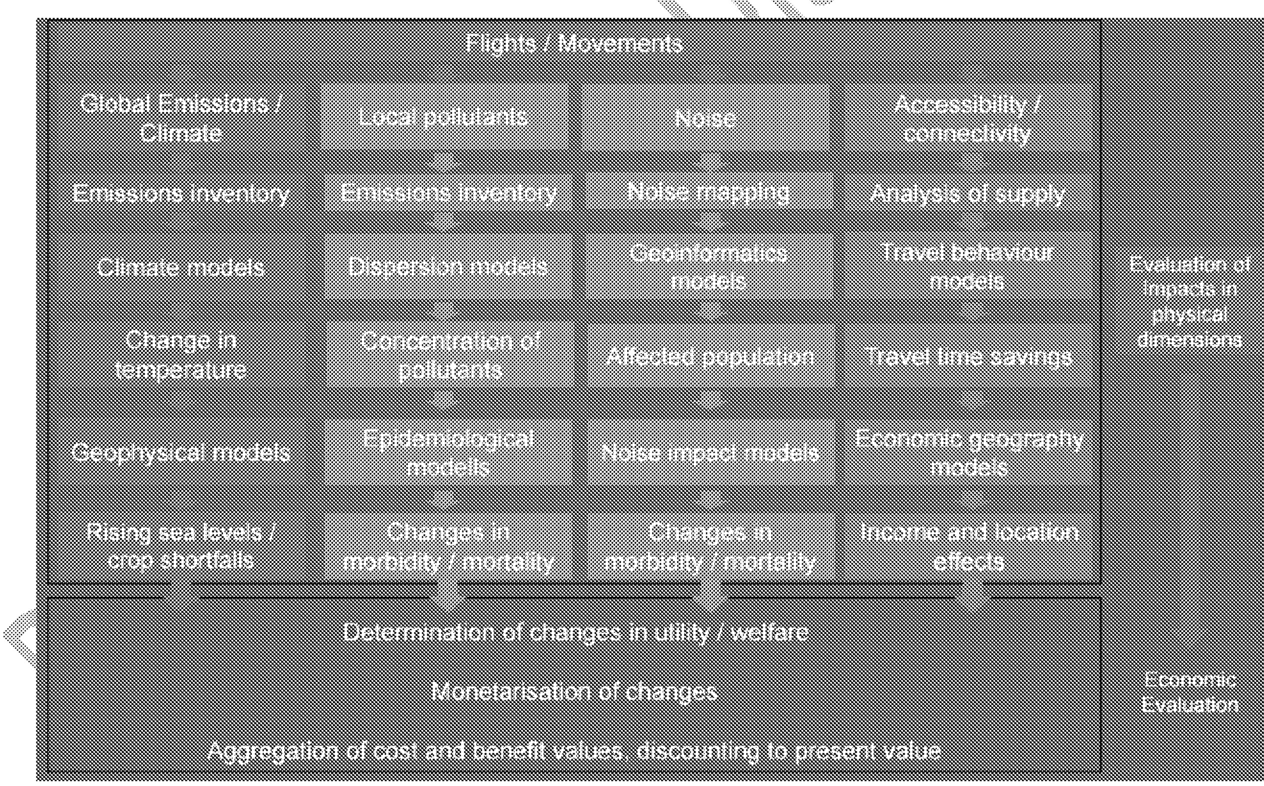


Figure 10: DLR's Framework for CBA

5.4.2 Summary of Model Inputs, Outputs, Modelling Approach and Assumptions

Module	Model Inputs	Source	Model Outputs	Modeling Approach	Assumptions
Noise	Nosie contours Population exposure		• Population impacted • Changes in morbidity/mortality Note: Exact Monetization term not available	• Noise impact models use noise contour or population exposure data • Based on the changes on morbidity/mortality, changes in utility/welfare is determined • Aggregation of cost and benefit values • Discount to present value	
Air Quality	Aviation emission data	ICAO Engine Emissions Data Bank [47]	• Changes in morbidity/mortality Note: Exact Monetization term not available	• Local emissions inventory is fed into epidemiological model • Based on the changes on morbidity/mortality, changes in utility/welfare is determined • Aggregation of cost and benefit values • Discount to present value	
Climate	Aircraft Movements Emissions Data	ICAO Engine Emissions Data Bank	• Global average temperature potential • Rising sea levels • Crop shortfalls • Damage cost in Euro	• Airborne emissions from Aircraft Movement Module is fed into Global Climate Module • Change in temperature and sea-level rise is calculated • Damage cost in € per ton of CO_2 equivalent is used to calculate the final damage cost	

5.4.3 **Case Study**: TBD

5.4.4 **Sample Outputs**

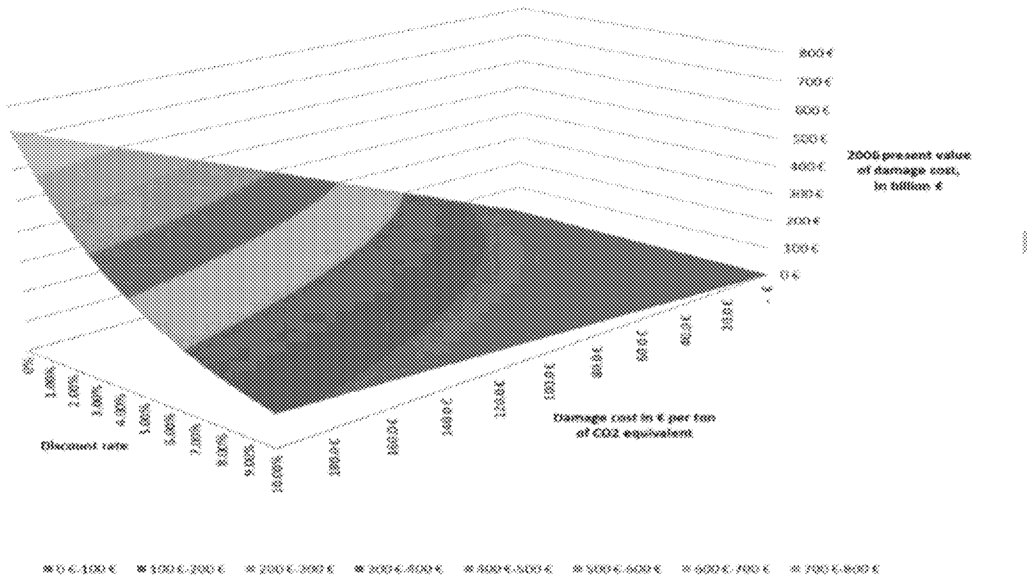


Figure 11: Example for the evaluation of climate effects of aviation with different damage costs

9. REFERENCES

[1] White House Guidance on the development of regulatory analysis, providing details on best practices. Circular A-4, September 17, 2003. https://www.whitehouse.gov/omb/circulars_a004_a-4/#5

[2] Canadian Cost-Benefit Analysis Guide: Regulatory Proposals, Treasury Board of Canada Secretariat, 2007. pp. 1-2. https://www.tbs-sct.gc.ca/hgw-cgf/finances/rgs-erdg/wwad-cqnf/col/analys/analys-eng.pdf

[3] Monetisation and Cost-Benefit-Analysis as Evaluation Tools in Air Transport, Institute of Air Transport and Airport Research, October 14, 2015. http://www.dlr.de/fw/en/desktopdefault.aspx/tabid-10333/17709_read-44344/

[4] Guidelines for Preparing Economic Analyses, National Center for Environmental Economics Office of Policy U.S. Environmental Protection Agency, December 17, 2010. Pp. xi. https://yosemite.epa.gov/ee/epa/eerm.nsf/vwAN/EE-0568-50.pdf/$file/EE-0568-50.pdf

[5] Research & SESAR, Eurocontrol. http://www.eurocontrol.int/articles/cost-benefit-analysis-or-business-case, assessed on 7/13/2016

[6] Economic Analysis of Investment and Regulatory Decisions-- Revised Guide, US Department of Transportation Federal Aviation Administration Office of Aviation Policy and Plans, January, 1998. pp. 12.
https://www.faa.gov/regulations_policies/policy_guidance/benefit_cost/media/ECONOMIC.pdf

[7] Economic Analysis and Environmental Assessment, Environment Department The World Bank, April 1998. pp. 4. http://siteresources.worldbank.org/INTSAFEPOL/1142947-1118039018606/20526257/Update23EconomicAnalysisAndEAApril1998.pdf

[8] White House Guidance on the development of regulatory analysis, providing details on best practices. Circular A-4, September 17, 2003. https://www.whitehouse.gov/omb/circulars_a004_a-4/#5

[9] CAEP/8 NOx Stringency Cost-Benefit Analysis Demonstration Using APMT-Impacts, ICAO, February, 2010. http://web.mit.edu/aeroastro/partner/reports/caep8/caep8-nox-using-apmt.pdf

[10] "Guidelines for Preparing Economic Analyses," U. S. Environmental Protection Agency (EPA), 2000.

[11] "The Green Book. Appraisal and Evaluation in Central Government.," UK HM Treasury, 2003.

[12] "Regulatory Impact Assessment Guidance," UK Cabinet Office, Better Regulation Executive (UK BRE), 2005.

[13] "The economic appraisal of environmental projects and policies - A practical guide," Organisation for Economic Co-operation and Development (OECD), 1995.

[14] "Guide to Benefit Cost Analysis in Transport Canada, TP11875E," Transport Canada, 1998.

[15] "Air Quality Guidelines for Europe, WHO Regional Publications, European Series, No. 91.," ed: World Health Organization (WHO), 2000.

[16] Kopp, R.J., A.J. Kuprick, and M. Toman, —Cost-Benefit Analysis and Regulatory Reform: An Assessment of the Science and the Art,‖ Resources for the Future Discussion Paper, No. 97-19, 1997.

[17] Krupnick, A., B. Ostro, and K. Bull, "Peer Review of the Methodology of Cost- Benefit Analysis of the Clean Air for Europe Programme," 2004.

[18] "Methodology for the Cost-Benefit Analysis for CAFÉ Vol. 1, 2 , and 3.," Clean Air for Europe (CAFÉ) Programme, 2005.

[19] https://aedt.faa.gov/

[20] He, Q., C. Wollersheim, M. Locke, and I. Waitz, "Estimation of the Global Impact of Aviation-Related Noise Using an Income-Based Approach," Transport Policy

[21] https://www.cmascenter.org/cmaq/

[22] Hasselmann, K., S. Hasselmann, R. Giering, V. Ocana and H. V. Storch, "Sensitivity Study of Optimal CO2 Emission Paths Using a Simplified Structural Integrated Assessment Model (SIAM)," Climatic Change, vol. 37, pp. 345 - 386, 1997.

[23] https://yosemite.epa.gov/ee/epa/eerm.nsf/vwan/ee-0564-114.pdf/$file/ee-0564-114.pdf

[24] He, Q., C. Wollersheim, M. Locke, and I. Waitz, "Estimation of the Global Impact of Aviation-Related Noise Using an Income-Based Approach," Transport Policy

[25] https://www.whitehouse.gov/sites/default/files/omb/inforeg/regpol/circular-a-4_regulatory-impact-analysis-a-primer.pdf

[26] https://www.epa.gov/air-emissions-modeling/2011-version-6-air-emissions-modeling-platforms

[27] See U.S. Office of Management and Budget website for detailed information about the social cost of carbon (SC-CO2) estimates, https://www.whitehouse.gov/omb/oira/social-cost-of-carbon. See the Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis (July 2015) at this site for the schedule of estimates, https://www3.epa.gov/climatechange/EPAactivities/economics/scc.html.

[28] See the 2016 final rulemaking to update the new source and performance standards for the oil and gas industry, [HYPERLINK "https://www3.epa.gov/airquality/oilandgas/may2016/nsps-ria.pdf"], and the Phase 2 Medium- and Heavy-Duty Greenhouse Gas Standards proposed rulemaking, https://www3.epa.gov/otaq/climate/documents/420d15900.pdf, for examples of recent applications.

[29] See the Phase 2 Medium- and Heavy-Duty Greenhouse Gas Standards proposed rulemaking for example of a recent analysis in a rulemaking: https://www3.epa.gov/otaq/climate/documents/420d15900.pdf.

[30] See the Phase 2 Medium- and Heavy-Duty Greenhouse Gas Standards proposed rulemaking: https://www3.epa.gov/otaq/climate/documents/420d15900.pdf.

[31] See the Tier 3 Vehicle Emission and Fuel Standards final Rulemaking: https://www3.epa.gov/otaq/documents/tier3/420r14005.pdf

[32] See the Tier 3 Vehicle Emission and Fuel Standards final Rulemaking: https://www3.epa.gov/otaq/documents/tier3/420r14005.pdf

[33] The CBA methodology – EMOSIA, Research & SESAR, EUROCONTROL. http://www.eurocontrol.int/articles/cba-methodology-emosia. Assessed on 7/13/2016

[34] Handbook on estimation of external costs in the transport sector, CE Delft, February, 2008. http://ec.europa.eu/transport/themes/sustainable/doc/2008_costs_handbook.pdf. Assessed on 7/13/2016

[35] HEATCO, 2005 P. Bickel (et al.) Developing Harmonised European Approaches for Transport Costing and Project Assessment (HEATCO): Universität Stuttgart, 2005 http://heatco.ier.uni-stuttgart.de/. Assessed on 7/13/2016

[36] TREMOVE economic transport and emissions model , K.U.Leuven and DRI , 2010. http://www.tmleuven.be/methode/tremove/home.htm. Assessed on 7/13/2016

[37] Lower NOx at Higher Altitudes Policies to Reduce the Climate Impact of Aviation NOx Emission, Delft, October 2008. Assessed on 7/13/2016 http://ec.europa.eu/transport/modes/air/studies/doc/environment/oct_2008_nox_final_report.pdf

[38] Aviation Integrated Modelling. http://www.aimproject.aero/index.html. Assessed on 7/13/2016

[39] ACcelerated CLadding and Integrated Machining. http://www.acclaim-project.co.uk/. Assessed on 7/13/16

[40] Integrated Noise Model, FAA Office of Environment and Energy. https://www.faa.gov/about/office_org/headquarters_offices/apl/research/models/inm_model/. Assessed on 7/13/16

[41] NoiseMap Simulation Model (NMSim), Department of Defense's (DOD), Developed by Wyle Laboratories.http://www.wyle.com/content/CapabilityB.aspx?Transportation+Environmental+Effects+Services. Assessed on 7/13/2016

[42] Enhanced Traffic Management System (ETMS) , Federal Aviation and Administration. https://www.fly.faa.gov/Products/Information/ETMS/etms.html. Assessed on 7/13/16

[43] European Centre for Medium-Range Weather Forecasts (ECMWF). http://www.ecmwf.int/. Assessed on 7/13/2016

[44] Schäfer, A et al., "Costs of mitigating CO2 emissions from passenger aircraft", November 23, 2015. http://www.nature.com/nclimate/journal/v6/n4/pdf/nclimate2865.pdf

[45] Monetisation and Cost-Benefit-Analysis as Evaluation Tools in Air Transport, Institute of Air Transport and Airport Research, October 14, 2015. http://www.dlr.de/fw/en/desktopdefault.aspx/tabid-10333/17709_read-44344/. Assessed on 7/13/2016

[46] Monetisation and Cost-Benefit-Analysis as Evaluation Tools in Air Transport, Institute of Air Transport and Airport Research, October 14, 2015. [HYPERLINK "http://www.dlr.de/fw/en/Portaldata/42/Resources/dokumente/2015neueposter/a1poster"] /_36_Monetarisierung_en_A1.pdf. Assessed on 7/13/2016

[47] ICAO Aircraft Engine Emissions Databank, European Aviation Safety Agency (EASA). https://www.easa.europa.eu/document-library/icao-aircraft-engine-emissions-databank. Assessed on 7/13/2016